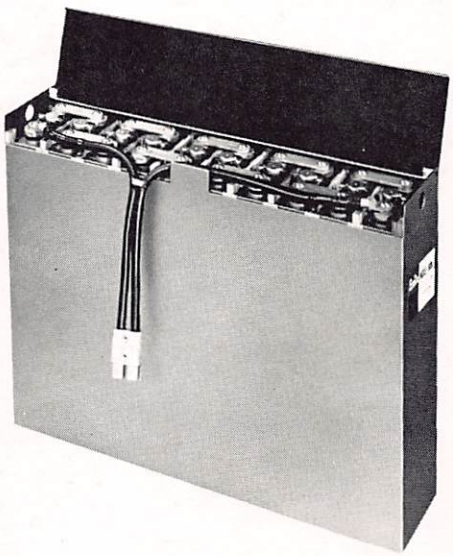
the NICKEL-IRON INDUSTRIAL STORAGE BATTERY



its fundamental principles, operation and care

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EXIDE INDUSTRIAL MARKETING DIVISION
The Electric Storage Battery Company

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THE NICKEL-IRON INDUSTRIAL STORAGE BATTERY

1. INTRODUCTION

Storage Batteries play a very important part in the life of every individual, both by direct contact in the automotive and possibly other fields, and indirectly by their extensive use in industry. In automotive use they are an almost indispensable convenience. In the industrial field they provide major savings in manpower, improved characteristics to related equipment, and reliable reserve power for many types of emergency.

The vast majority of storage batteries fall into two groups or types, the lead-acid battery and the nickel-alkaline. The lead battery is the one most commonly known because of its automotive use, and also because it has a wider range of application in other fields. However, the nickel-alkaline type, while not used as diversely, does have wide industrial application, primarily in the operation of electric industrial trucks, the lighting and air conditioning of railway cars, and various stationary battery uses. It is with this type, specifically the NICKEL-IRON-ALKALINE, that this booklet deals.

Like other batteries, the characteristics which make this nickel type a vital item of equipment are these:

- It provides a source of power for moving vehicles and/or, to operate or control other apparatus on such equipment.
- It can provide a reserve source of power in stationary applications, so that equipment can continue to operate when normal power fails.
- It can be used as a "pure" direct current source for laboratory or similar purposes.
- One distinct advantage of this type is that it can be stored, almost indefinitely, without attention and in any state of discharge. (See Sec. 17).

With a better understanding of these batteries, their advantages and economies can be better realized.

2. FUNDAMENTAL PRINCIPLES

a. This battery, like any other, has three essential components, — positive active material, negative active material and electrolyte. The nickel-iron battery, however, is unique in many respects, both its chemistry and physical properties being different from other types.

In a fully charged cell the positive active material is essentially nickel oxyhydrate (NiOOH), the negative is metallic iron sponge (Fe) and the electrolyte potassium hydroxide (KOH) and water with the addition of lithium hydroxide. The chemical reactions during discharge produce certain intermediate transitory compounds, but the end result is a transfer of oxygen from the positive to the negative, leaving the positive

as nickel hydroxide $Ni(OH)_2$, and the negative as iron hydroxide, $Fe(OH)_2$. Neglecting the intermediate reactions, the end formula may be considered as:

$$2\ NiOOH \cdot H_2O + Fe \underset{\text{CHARGE}}{\overset{\text{DISCHARGE}}{\rightleftharpoons}} 2\ Ni(OH)_2 + Fe(OH)_2$$

It will be noted that the electrolyte takes no part in the chemical reaction in the sense that its composition is changed. It does, however, act as a transfer agent by "accepting" oxygen at the positive during discharge and "depositing" it at the negative. This does not mean, of course, that the oxygen is transferred as a gas, but that it dissociates from the positive and combines with the negative at the same time. On charge, conversely, the action is reversed and the positive and negative materials revert to their original charged state.

As in any type of cell, when the charging current is greater than the cell can "absorb", the excess is expended in dissociating the water of the electrolyte into its components, hydrogen and oxygen, which are given off as gases. This is the primary reason for the required addition of water to battery cells. (Also see "Gassing", Sec. 12).

b. The active material in both cases is in the form of finely ground powder and requires a "container" to give it a physical form and provide a conductor to the external circuit.

The positive material is encased in perforated nickel plated steel tubes, made by spirally winding a flat strip into tubular form. The ends of these tubes are closed by crimping, and the tubes themselves are reinforced at intervals by annular steel rings. Inasmuch as the active material is a poor electrical conductor, it is interspersed with alternate layers of metallic nickel flake to increase its conductivity to acceptable levels.

The negative material is encased in flat, perforated, nickel plated steel pockets to accomplish a similar result. Due to the nature of this material no additional conductive material is required.

In both cases the "plate" is formed by grouping the desired number of positive tubes or negative pockets and crimping or welding them together or to a nickel plated sheet steel frame.

3. PHYSICAL CONSTRUCTION (See Fig. 1)

It has already been mentioned that the essential active materials are encased in steel tubes or pockets, these being held in position in a sheet steel frame to form a PLATE. These frames have an extension at the top, known as a LUG or EAR in which there is a hole to receive a connecting ROD. The desired number of plate lugs, with intermediate spacing washers to separate the plates by the required

distance, are placed over the rod and retained by nuts at either end. Also on the rod, at the center, is the lower part of the POST which extends upwards as the external connection to the circuit. This assembly of plates, rod and post is known as a GROUP.

The plates of the positive and negative groups are intermeshed between each other and prevented from coming in contact by round hard rubber or plastic PINS or INSULATORS. This assembly of positive and negative groups and insulators is known as an ELEMENT.

The JAR (or CONTAINER) is of nickel-plated sheet steel. Inasmuch as this is an electrical conductor, it must be insulated internally from the element, and also from the posts where they pass through the top or COVER. The insulation from the element is by hard rubber or plastic sheet, and hard rubber bushings or GLAND CAPS encircle the posts.

Inasmuch as the cell containers are metal, each cell must be insulated from the adjoining ones and from any other electrical conductor. This is done in either of two ways. The sides of each container may be equipped with small round extensions known as BOSSES which project into rubber BUTTONS in holes in the sides of a wood crate or TRAY. The cell is suspended from these bosses, thus insulating it from adjoining cells. This method of suspension also permits the bottom of the tray to be open for ample ventilation, this being necessary in alkaline type cells to dispose of the heat generated on both charge and discharge.

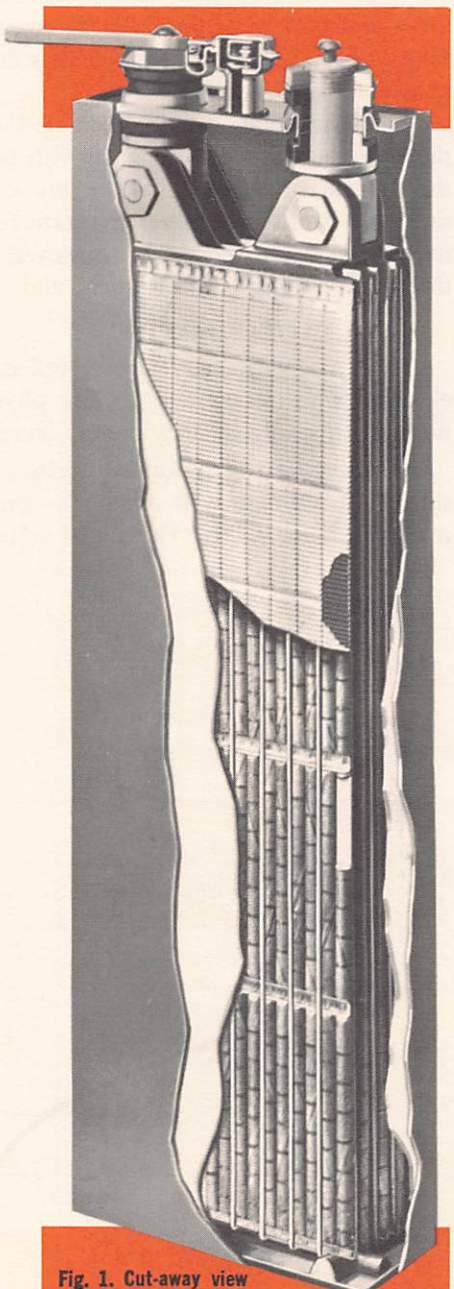


Fig. 1. Cut-away view of typical Nickel-Iron Industrial Cell.

As additional insulation and protection from moisture, the entire tray, and the sides and bottom of the cells are covered with a black insulating paint known as ESBALITE. The top of the cells is covered with a resinous, varnish-like coating known as ESBALINE.

Another method is to assemble the cells in steel trays or boxes. In this case the containers are not equipped with bosses but rest on individual rubber pads on the bottom of the tray. They are coated with an insulating plastic film and separated from each other by vertically corrugated plastic sheets. This type of more compact assembly is, however, usually considered less satisfactory from the standpoint of both electrical and heat insulation.

4. VOLTAGE

The voltage of any battery cell is an inherent characteristic of the chemical elements which constitute it. The physical size or number of plates of a cell do not affect its voltage, they merely increase the cell capacity in ampere hours.

The voltage of nickel-iron cells is usually referred to as being 1.2 volts, — thus a 10 cell battery is nominally considered a 12 volt battery, a 30 cell battery a 36 volt battery, etc. The actual voltage at any time, however, will depend as to

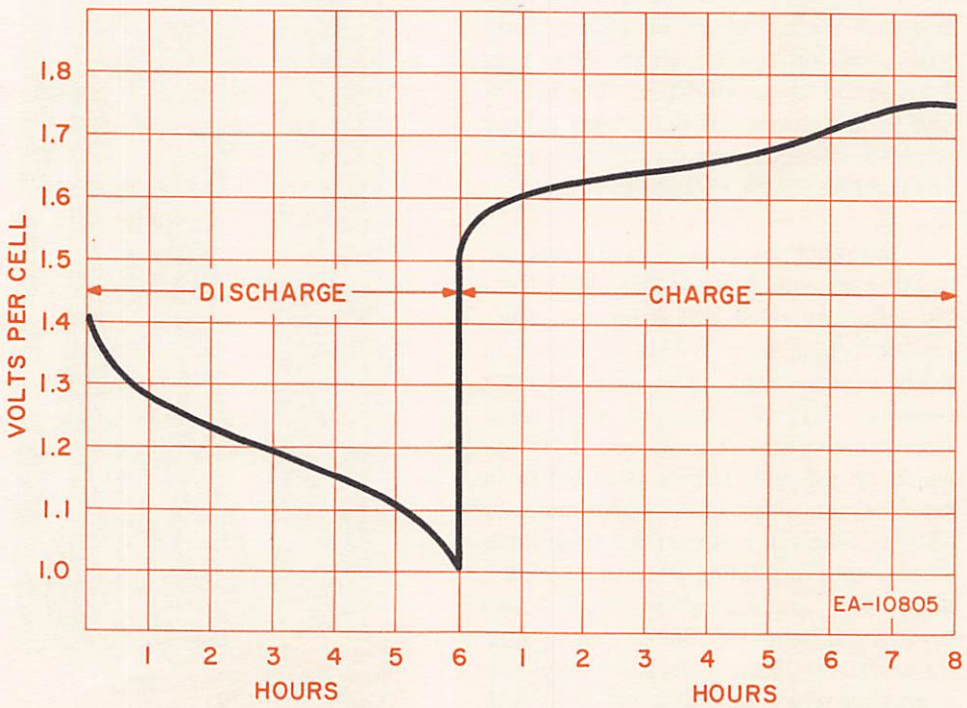


Fig. 2. Typical Voltage Characteristics during a constant rate discharge and recharge.

whether it is on open-circuit, on discharge, or on charge and in the latter cases, the current rate and the state of charge.

The open circuit voltage will vary roughly between 1.25 and 1.35 volts, but its relation to the state of charge is not sufficiently definite to be used as an indication of that condition.

When placed on discharge, the voltage will immediately decrease to a lower value due to the effective internal resistance of the cell. This voltage "drop" will increase with an increase in discharge current. Also at any constant rate of discharge, the voltage gradually decreases until, as the cell approaches exhaustion, it falls below a value where it is no longer effective for the application to which it is put. This value is referred to as the "final" voltage. It varies with the rate of discharge, being lower at higher rates and vice versa. The most commonly used value is 1.0 volt per cell, although either higher or lower ones may be more suitable for particular uses. See Figs. 2 and 5 for discharge curves at various rates.

Conversely, when placed on charge, the voltage rises sharply and then follows a distinct pattern throughout the charge, to a maximum value varying with the charging rate. At the rates most commonly used, this maximum voltage is 1.7 - 1.8 volts per cell. See Fig. 7 for typical charge-voltage curves, and Sec. 8 on charging.

5. ELECTROLYTE

a. As previously mentioned, the electrolyte is a solution of postassium hydroxide (KOH) and water with the addition of lithium hydroxide. While necessary to the chemical reaction, it is not significantly changed by it throughout the normal range of charge and discharge and therefore the specific gravity does not indicate the state of charge of the cell.

The specific gravity of the electrolyte of a new cell is about 1.210 - 1.215 at the normal electrolyte level, at 77°F. This gravity slowly decreases over months or years due to loss from spray during charge, and possible spillage. The electrolyte also tends to carbonate due to contact with the air. When the gravity decreases to about 1.160, it definitely affects the capacity and the operation of the cell, and the entire solution requires renewal (See Sec. 16d). This may be necessary several times during the life of the battery.

The only time that there is any significant change in the specific gravity is if the discharge is carried beyond its normal limits, down to or near zero voltage, as when cells are put in storage (See Sec. 17). This drives much of the lithium from the plates into the electrolyte and its gravity may rise 25 to 35 points (.025 - .035). This action is reversed, of course, when the cells are again charged.

b. Specific Gravity Correction — The specific gravity as actually read with

a hydrometer will vary with changes in temperature. This is not due to any characteristic of the cell, but simply to the fact that the solution expands with a rise in temperature and contracts as the temperature falls. With expansion it becomes less dense and therefore the specific gravity is lower. Likewise with contraction the gravity rises. This change is about 1 point of gravity (.001) for each 3°F.

The gravity of a cell also changes as the electrolyte level changes with the use and addition of water. As the level falls due to water loss from gassing, the solution becomes more concentrated, raising the gravity. This change is reversed by addition of water to the previous level. In this case the difference between the gravity at various levels is a function of the physical design of the cell. While it varies widely for that reason, an average value may be considered to be 4 to 6 points of gravity per ¼" change in level.

It can be seen from the above that to accurately compare specific gravity readings taken under different conditions, they must be corrected to a common standard, this being the normal or specified electrolyte height of the cell, and a temperature of 77°F. The "corrected gravity" is what it *would read* under these standard conditions. To do this:

- Add one point (.001) of gravity for every 3°F above 77°, or subtract 1 point for every 3° below 77°.
- Subtract 5 points of gravity (assuming the cell has a 5 point change per ¼") for every ¼" that the level is below its normal position, or add 5 points for every ¼" above normal.

Example: Specific gravity reads 1.220 at 89°F and ½" low level. 89°F — 77°F = 12° ÷ 3 = 4 points to be added. ½" low level = 10 points to be subtracted. Net result, subtract 6 points, — "corrected" gravity is 1.214.

c. Under normal operating conditions there is little danger of the electrolyte freezing, but at quite low temperatures and with the specific gravity reduced below normal, there is that possibility. At the temperatures shown in the following table, the electrolyte will not freeze unless the gravity is lower than indicated.

Temperature Degrees F	Specific Gravity At Same Temp.	Corr. to 77°F
+20	1.095	1.075
+10	1.145	1.120
0	1.180	1.150
—10	1.210	1.180
—20	1.235	1.205
—30	1.255	1.225
—40	1.280	1.240

d. Alkaline electrolyte for nickel-iron cells is usually furnished in two specific gravities (a) 1.200 - 1.210, known as Refill Electrolyte, and (b) 1.240 - 1.250, known as Renewal Electrolyte.

The former is used primarily for replacing accidental spillage loss and the latter for complete replacement when required by low gravity. See Sec. 16d.

6. CAPACITY

a. The capacity of a storage battery, its ability to deliver power, is usually expressed in ampere hours, which is the product of the discharge in amperes over a number of hours. However, a simple figure such as 100 ampere hours, has little significance unless it is qualified by the various factors which influence the capacity, and also by the application for which it is intended. The principal factors which must be considered are:

- Discharge Rate
- Temperature
- Final Voltage

b. *Discharge Rate.* The higher the discharge rate in amperes, the less total ampere hours a battery will deliver under otherwise similar conditions. This relationship varies slightly with different cell types, but is generally represented by the graph in Fig. 3.

The primary reason for this is the internal resistance of the cell which causes a voltage drop or loss within the cell itself. The higher the current being discharged, the greater is this internal voltage drop and, therefore, the less voltage is available for the external load. This means that the

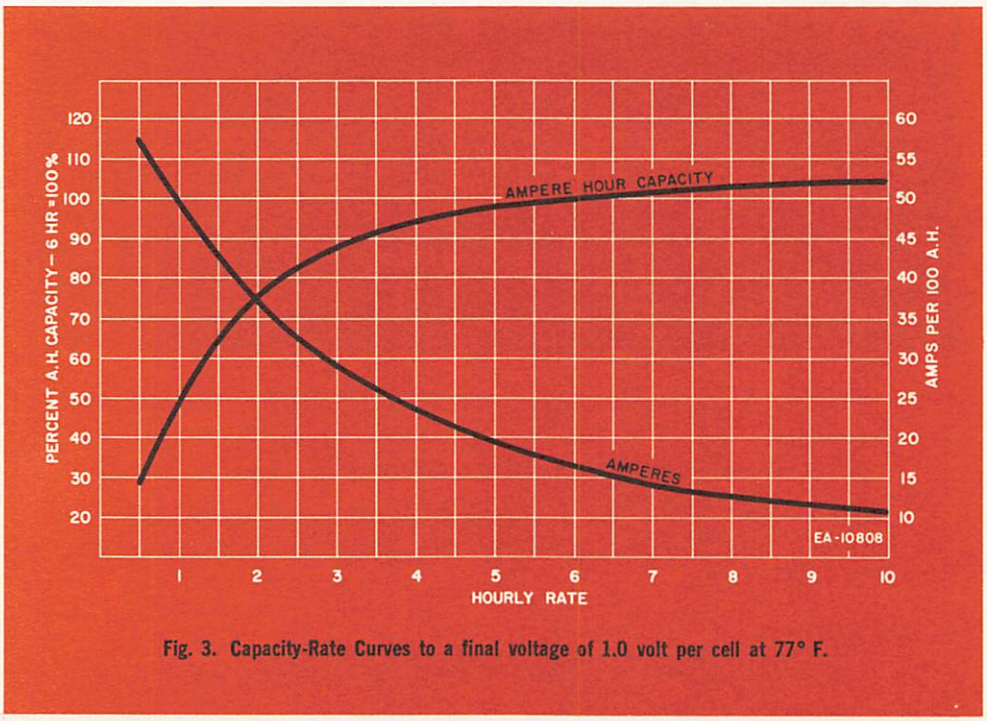


Fig. 3. Capacity-Rate Curves to a final voltage of 1.0 volt per cell at 77° F.

"final" voltage is reached earlier, with a resultant loss in capacity.

The discharge rate most commonly used as a standard reference for alkaline batteries has been the 5 hour rate, although some are rated on a 6 hour basis. Actually the difference between these two is only a couple of percent. Of course, other hourly ratings can be supplied to cover applications requiring them. All such ratings are equally correct, as long as they are properly specified and understood.

c. *Temperature.* In common with many other chemical reactions, those of a storage battery are accelerated at higher temperatures. In addition to this, the resistance and viscosity of the electrolyte are reduced at higher temperatures, it having a negative coefficient of resistance. Thus the voltage drop within the cell is less and the resultant capacity is greater. Conversely, at lower temperatures the capacity is reduced. Fig. 4 gives a general

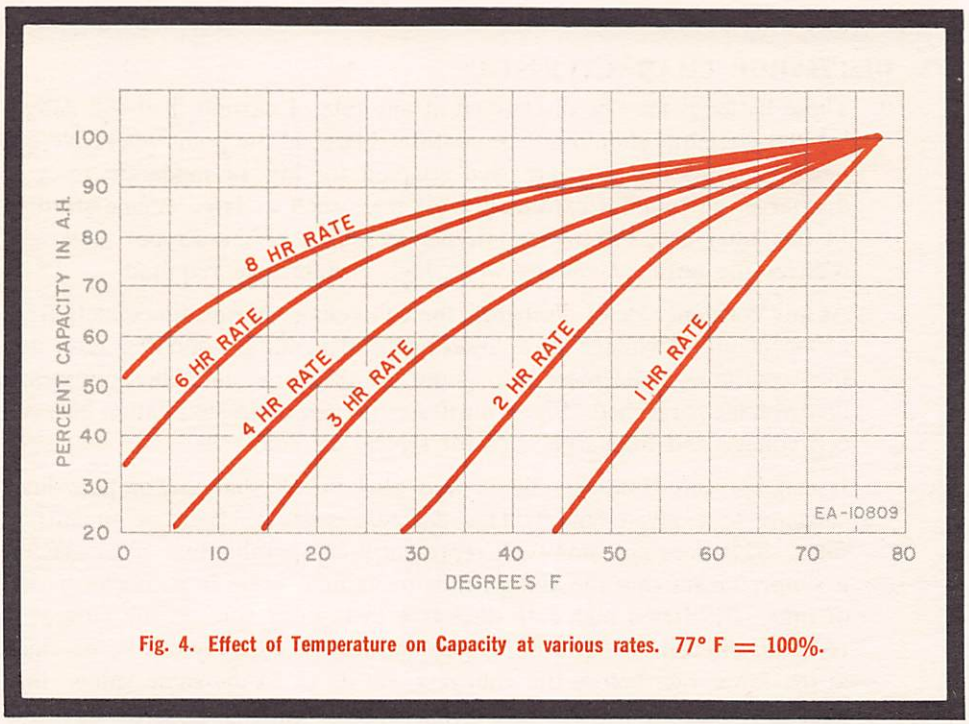


Fig. 4. Effect of Temperature on Capacity at various rates. 77° F = 100%.

indication of this temperature effect at various discharge rates.

A "standard" reference temperature of 77°F (25°C) is most commonly used, and is assumed unless otherwise specified.

d. *Final Voltage.* This term is used to define the voltage commonly accepted as the practical minimum for a given application. It varies, therefore, with the use to which the battery is put, being higher for low rates of discharge and lower for high rates. In either case it represents the point beyond which the voltage will drop rapidly to less than a useful value.

While the value will vary as mentioned above, a final voltage of 1.0 volt per cell is most commonly used for applications of alkaline batteries.

It can be seen from the above, that to properly specify or identify battery capacity, the rate of discharge, temperature and final voltage must all be taken into consideration.

7. DISCHARGE CHARACTERISTICS

a. These batteries may be discharged at any rate of current they will deliver but the discharge should not be continued beyond the point where the cell nears exhaustion. They are well adapted for low or moderate rates of discharge, but not for extremely high rates such as large engine starting. In this latter case the higher internal resistance of these types materially reduces the terminal voltage when high currents are required.

At any constant rate of discharge, the cell voltage drops immediately from its open circuit voltage to a lower value depending upon the rate, and then continues to decrease throughout the discharge until the appropriate final voltage is reached. Fig. 5 illustrates the approximate relation between cell voltage and discharge rates for typical alkaline cells.

It can be seen from this figure and also Fig. 3 that the ampere hour capacity to a given final voltage decreases with an increase in current rates. This does not, however, represent a comparable loss of energy, — it simply means that the voltage falls to its final value in a shorter period of time. If, after a high rate discharge to a given voltage, the current is reduced, the cell voltage will recover and further capacity can be obtained at the lower rate before the voltage again drops to the same value. It is generally true that when *decreasing* current rates are used, the total ampere hour capacity of a battery at a given hourly rate (or nearly that amount) may be obtained during that time period, regardless of higher than average rates at the beginning. This does not hold, of course, if the high rates are at the end of the discharge. See Fig. 6.

During discharge there is an appreciable rise in temperature due to the heat losses (I^2R) in the cell, this increasing with an increase in current rates. During a typical discharge of 6 to 8 hours, this may cause a rise of 20 to 30°F or more if reasonable ventilation is lacking. (See Sec. 13). Where practical, it is well to limit the discharge to 80% of capacity, particularly if moderately high rates are used, to minimize this temperature rise.

b. The state of charge of an alkaline battery cannot be determined as readily as with other types. The specific gravity does not change appreciably during discharge or recharge, and a gravity reading, therefore, has no significance. The only practical means is to read the voltage of a pilot

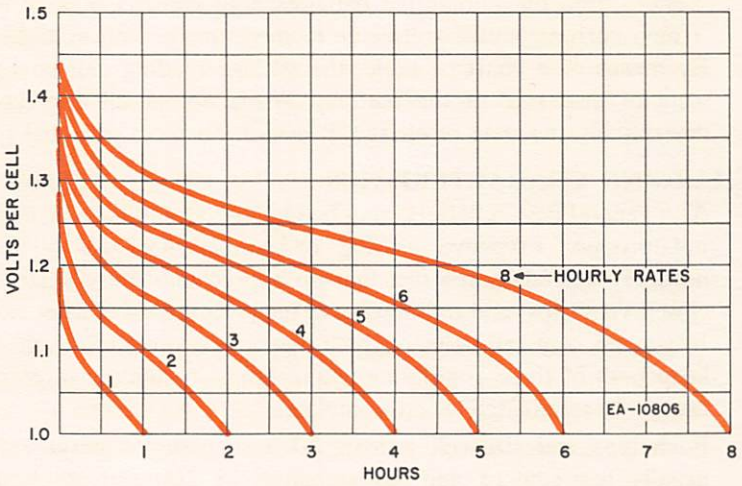


Fig. 5. Time-Voltage Discharge Curves, at various rates, to a "final" voltage of 1.0 volt per cell.

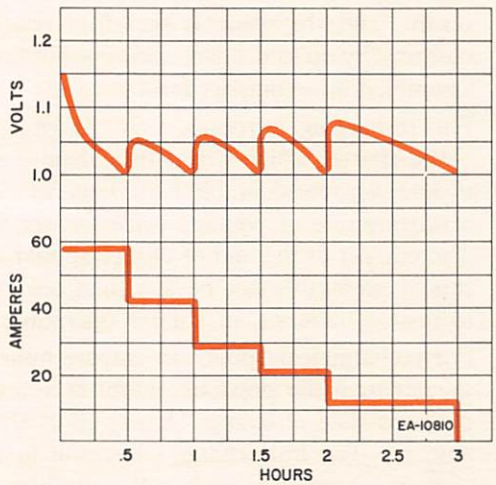


Fig. 6. Effect of decreasing discharge rates on cell voltage.

cell under a momentary high rate discharge. A device known as a "Test-Fork" is available for this purpose. It is similar in principle to the "tester" used on automotive batteries, and consists of a resister drawing a high current, and a voltmeter to measure the cell voltage at the time. By means of a chart or table, the voltage reading can be related to the state of discharge of the battery. While not at all a precise means of determining the state of charge, it does meet most practical requirements.

8. CHARGING CHARACTERISTICS

a. As a general rule, a battery may be charged at any current rate which does not produce excessive gassing or temperature rise. The gassing is normally judged by the fact that no appreciable spray passes through the closed vent caps, and the maximum temperature should not exceed 115°F. In general, any cell voltage which does not exceed 1.70 volts per cell will keep both of these conditions within limits, assuming, of course, that the charge is terminated when complete.

Each type and size cell is assigned a suggested "charge rate" which is usually between 15 and 20 amperes per 100 ampere hours of rated capacity. This is determined primarily from the temperature rise which results, and the value is therefore relatively higher for cells which are customarily spaced apart allowing air flow between them, than for those assembled in a compact mass.

For recharging purposes, this charge rate can be used throughout the entire charge, which would thus require a 6 to 8 hour time period. There is, however, considerable latitude permissible in the charge rate to be used, a starting rate of perhaps twice the specified value not being prohibitive. The current at the end of charge should not exceed the specified rate, but should preferably not be less than one-third of it. (This does not apply to floated batteries, or similar operating methods.)

For recharging purposes an ampere hour input approximately 25 percent greater than the previous output is necessary to return the battery to the previous state of charge. Every effort should be made to give the correct amount. Too little charge will result in reduced capacity, and too much, while not harmul *as such,* will cause high temperature and excessive water requirements which in turn can bring internal damage to the cells.

The detection of improper amounts of charge is primarily a matter of

checking the causes of low capacity, higher than normal temperatures or water requirements. It is difficult to specify generally the quantity of water which a given battery will need, as this varies with the work cycle and charging methods. For a specific situation, however, the manufacturer can usually estimate with reasonable accuracy what may be expected.

Current and voltage values indicated above are representative for "normal" temperatures of 70-80°F and batteries in good condition. Differences in temperature, battery and/or operating conditions will, however, cause variations.

While lack of sufficient charge will reduce the capacity of alkaline batteries, no permanent harm results. One or two discharge and recharge cycles will usually return them to full capacity. With proper operation, no routine "equalizing" or special charges are required.

Practical charging can best be understood by considering some of the actual methods used:

b. *Cycle Charging.* This represents a routine recharge following a partial or complete discharge and is best illustrated by industrial truck service

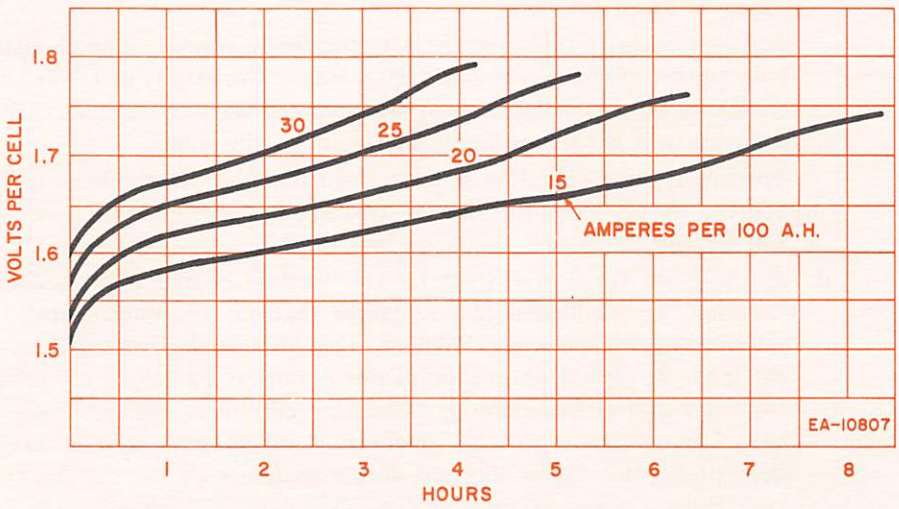


Fig. 7. Typical Charging Voltages at various current rates.

in which the battery powers the truck during the day's work and is recharged during the night. The current rate is usually one which has an average value about equal to the specified charge rate. With some types of equipment this will remain at a nominally constant value throughout the entire charge — with other types it will "taper" somewhat, starting higher and finishing lower than the specified value. For this charging, an 8-hour period is usually assumed to be available, and an average value of the specified rate will complete the charge in that time or less. It should, of course, be stopped automatically.

c. *Floating Charge.* In this method a battery has impressed across its terminals a constant voltage just sufficiently higher than its open circuit value to maintain it in a state of full charge. The battery can be said to be "balanced" across the charger and load, all of these being connected directly in parallel. The charger normally carries the load and furnishes the necessary "floating current" to the battery. In the event of power or charger failure, the battery carries the entire load. Upon resumption of power, the battery at first draws a comparatively high charging current, which tapers off as the recharge progresses until a normal floating condition is again reached.

   For the floating of typical stationary batteries, a voltage value of 1.50-1.55 volts per cell is commonly used. To maintain the battery in a fully charged condition, approximately 4 to 6 milliamperes per ampere hour of battery capacity, will be drawn at the mid-point of this range.

   For this type of operation it is assumed that the ampere hour discharge actually drawn from the battery (except, of course, is an emergency) will be small.

d. *Partial Float* (or Partial Cycle). This method of operation is similar to "floating" as mentioned above, except that the charging source is not continuously available, and during such periods the battery must carry the load. A typical illustration of this is railway passenger car operation for lights and air-conditioning. Charging current is available only when the car is in motion, as the generator is driven from the car axle, and the battery must supply the load during station stops.

   Under these circumstances, the floating voltage must be carried at a comparative high value in order to replace the discharge during periods

of operation. The value of this floating voltage may range anywhere from 1.55 to 1.70 volts per cell, with 1.65 being a representative figure. The lower values would be used for schedules with long runs and few stops and the higher voltages for local runs with frequent stops. Climatic temperature ranges also influence the voltage selected as lower temperatures require a higher voltage for the same current input, and vice versa.

e. *Two-Rate Charging.* This refers to a system whereby the early portion of a recharge is given at a comparatively high rate, and the latter portion at a much lower rate. This is seldom used for frequent, regular, recharging of alkaline batteries, as the specified rate can be used continuously throughout a charge which can be completed in 6 to 8 hours, and it is seldom necessary to recharge in less than that length of time.

   A two-rate charge is frequently applied, however, to stationary systems where the demands on the battery are irregular and difficult to estimate. This consists of a "low-rate" equal to any continuous load, plus a sufficient maintenance current for the battery itself, and an intermittent "high rate" to replace the discharge of any other loads which may come on the system. This high rate may be started either by a time-switch on a periodic basis, or by a function of the equipment which causes the additional load. The high rate may be terminated by a voltage relay which operates when the battery approaches full charge, or by the cessation of the additional load itself. This type of system is frequently applied to certain railway signal uses.

f. *Continuous Average Current.* In all of the above charging methods, the amount of charge is reguated to the actual requirements of the battery, on the assumption that the amount of discharge cannot be reliably estimated. There are certain applications, however, where the total discharge over a period of time (perhaps 24 hours) is reasonably uniform although the rate may vary widely during that period. Some railway signal installations are a good example. The discharge current may be very light when no trains are passing and quite heavy while they are, yet the total from day to day is much the same. Under this condition a constant current charge rate can be applied, this being the average value of the load plus the necessary amount to maintain the battery itself. Thus, when the load is above average, the battery is discharging and supplying

the remainder — when below average it is being recharged.

This method employs less expensive equipment than others, but works out quite satisfactorily in compatible services. It is necessary, however, to give a manual recharge following any large unanticipated discharge.

g. *Trickle Charge.* This is employed where it is desired to keep fully charged a battery required only for (presumably rare) emergency use. It consists of a constant current input just sufficient to overcome the battery's internal losses. Under typical conditions this would require about 4 to 6 milli-amperes per ampere hour of battery capacity. A lower input is sufficient if less than full capacity is needed. Of course, a separate recharge is necessary following an emergency discharge.

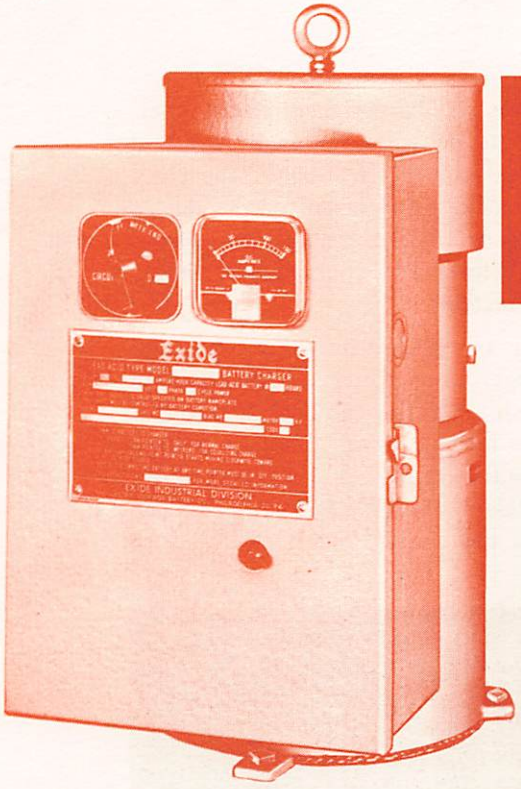
9. CHARGING EQUIPMENT AND CONTROLS

a. The Direct current required for charging can be obtained from:
- A direct current power system
- An AC-DC motor-generator set
- An AC-DC rectifier

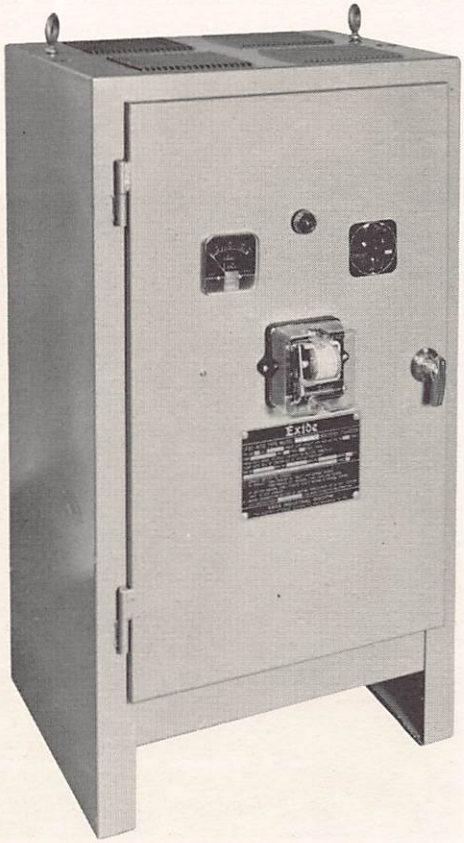
Inasmuch as DC power systems, either from utilities or in industrial plants, are no longer common, practically all battery charging is from motor-generator sets or rectifiers. All of the above sources can provide, either inherently or by various means of adaptation, proper charging for most battery applications.

Quite evidently, the charger chosen for a particular battery must have a DC voltage higher than that of the battery and a current capacity adequate to replace the ampere hours discharged, under the system design, in the desired time.

b. *Cycle Charging.* The majority of chargers currently sold for this purpose, either motor-generators or rectifiers, are for charging an individual battery. (To these can be added, if desired, a "Sequence Control" which enables two batteries to be charged sequentially, one after the other, without manual attention). Where large numbers of batteries are in use, a "multi-circuit" charging system is desirable; this consisting of one or several large generators which supply any number of individual charging panels. Rectifiers are available as a power source for these multi-circuit systems, but are less common than motor-generators.



Vertical Motor-Generator Set for cycle recharging.



Silicon-Diode Rectifier for cycle recharging.

The individual or "single circuit" chargers can be designed, either inherently or by the use of suitable controls, to deliver a nominally constant charging rate. While a precisely constant current is possible, the characteristic is usually such that a small reduction in current occurs during the charge — starting at perhaps up to 20 or 25 percent above the average value and finishing at an equal amount below. This characteristic can be inherent in either a motor-generator or rectifier.

In the multi-circuit system the generator or rectifier provides a constant voltage DC bus throughout its load range. Each battery is connected to this bus, through a ballast resistor of such a size that the current throughout the charge is sufficiently close to the average value. The bus voltage commonly used is 2.0 volts per cell, although values somewhat above or below this are also practical. With this method, there is always some decrease in the current rate throughout the charge, but it can be kept

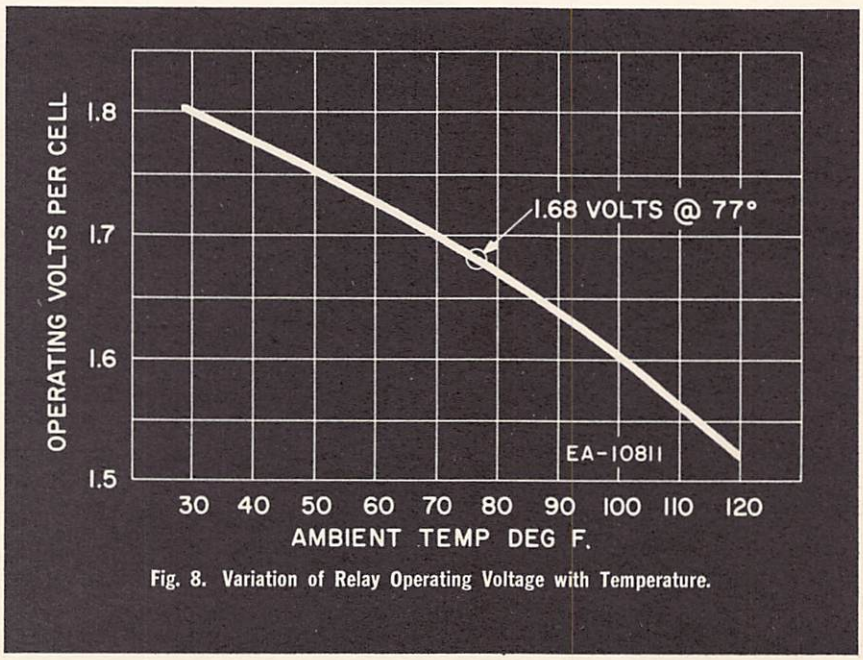


Fig. 8. Variation of Relay Operating Voltage with Temperature.

well within the desired values.

Such charging may be automatically terminated by one of several methods, depending on the particular type of cell used, and the charging equipment available.

One of these is the "voltage-time" method, employing a sensitive voltage relay and a time-switch or "clock." During charge there is a gradual rise in battery voltage which can be sensed by the voltage relay at a value representing a certain state of charge. At this point the relay starts the time-switch which is pre-set to run a stated time and then stop the charge. Inasmuch as the voltage of a battery on charge is affected by temperature changes, this relay must be "temperature compensated" to correspond with the battery characteristic. It operates at lower voltages at higher temperatures, and vice versa, and thus functions at the same state of charge at any temperature. See Fig. 8. Nominal voltage value used is 1.68 volts per cell at 77°F. Time-switch interval is usually about 2½ hours.

Another method is by means of a time-switch which is pre-set, at the beginning of charge, for the total charging time as required by the amount of discharge. This proper time interval is determined by using a "Test Fork" which measures the voltage of an individual cell under an artificial load, the value thus read being an indication of the state of discharge. By means of an appropriate chart, this voltage is translated into the required time in hours under the existing charging rates. Any other means of reliably estimating the average daily requirements may also serve as an indication of the time switch setting.

A third method is by the use of an ampere-hour meter connected in the battery circuit at all times. This meter has an indicating pointer which turns clockwise during discharge indicating the amount in ampere hours. When on charge the current flows in the opposite direction and the pointer of the meter turns counter-clockwise, returning to its starting point, and thus indicating that the battery is again fully charged. The necessary 25 percent additional ampere hours required on charge is obtained by designing the meter to run slow, by that amount, in the charge direction. An auxiliary contact at the "full" position of the meter functions to stop the charge via a contactor in the main circuit. At one time, these meters were in quite common use, but they have now been largely superseded by one of the other methods described above.

c. *Partial Cycle.* The most common application of this method with alkaline batteries is in railway carlighting and air-conditioning service. There the power source is a DC generator driven from the car axle. Inasmuch as this operates at various speeds, it cannot inherently provide proper charging characteristics. Therefore a "regulator" is used to maintain nominally constant voltage up to the generator's rated capacity.

These regulators, in principle, are the same as used in automotive, marine, and other services where the generator necessarily operates at varying speeds and only during certain periods of time. They usually include three essential components:

- An Automatic Switch or "cutout." This connects the generator to the system whenever its voltage (as determined by its speed) is sufficiently high for charging purposes, and disconnects it when its voltage drops to below a useful value.
- Voltage Regulator. This maintains a nominally constant voltage on the battery and system during operation, to assure proper functioning of the connected equipment and proper charging of the battery.
- Current Regulator. This protects the generator from overload by limiting its output to its rated maximum.

The majority of these regulators in present use are electro-mechanical devices, achieving their purpose by varying the current in the generator field. Recently, however, electronic equipment has been developed, which accomplishes the result statically.

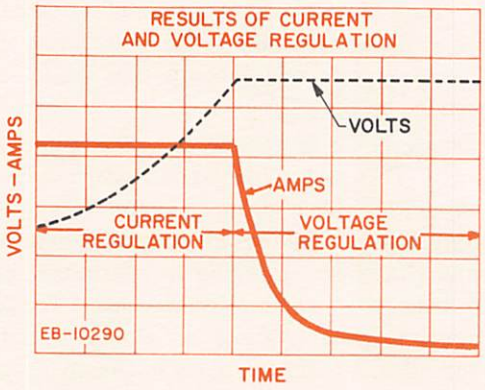


Fig. 9. Effects of "Regulators" with Voltage and Current Regulation.

In this type of charging the current may be initially limited by the capacity of the charger. Later it will decrease to a low value when the battery becomes fully charged and continue as long as the generator is in operation. The only complete "termination" is when the generator stops. See Fig. 9.

d. *Floating Charge.* The equipment for true float-charging can be either a generator or rectifier so designed or controlled that it maintains a constant voltage up to the limit of its capacity. Any attempt to appreciably overload it simply results in a lower voltage. It normally is in continuous operation.

Equipment for other applications, which usually are quite small from a capacity standpoint, is generally a simple rectifier with the current controlled by transformer taps, resistors or other means.

10. EFFICIENCY

The efficiency of a battery — energy input versus energy output — will vary widely depending on the circumstances of use. A certain amount of energy is required to maintain it, even without any use, so that the greater the amount of proper use, the higher the efficiency will be. Nominally the relation between a normal discharge and recharge is the basis on which efficiency is considered.

This may be expressed in two ways — as the ampere-hour efficiency or the watt-hour efficiency. In terms of ampere hours, it is usually considered that the recharge should equal 125% of the discharge giving an efficiency of 80%. However, the average voltage on charge is consideraly higher than on discharge, in the approximate proportion of 35%, giving a voltage efficiency of 75%. Combining these two (80 X .75) results in a watt-hour (total energy) efficiency of about 60%, which can be considered a representative figure.

11. LOCAL ACTION

This term is used to indicate the internal losses of a cell, either standing on open circuit or on float charge. On open circuit this may be represented by the loss in capacity over lengthening periods of time. On float or trickle charge it is usually measured by the amount of current required to maintain it in a fully charged condition. See Sec. 8g. In either case these losses increase at higher temperatures and with the age of the cell.

12. GASSING

As mentioned earlier, during charge there is a certain amount of energy which the cells cannot absorb and this is dissipated in the form of "gas." This gas actually consists of oxygen evolved at the positive plate and hydrogen at the negative.

In nickel-iron cells these gases are evolved during the entire charge, the amount increasing however as the charge progresses. The proportion varies during the charge, but when the cell is fully charged it represents the relation in which they exist in the water which is being dissociated, — two parts of hydrogen to one of oxygen.

In this type of cell the positives "retain" a certain amount of oxygen during the charge and this continues to evolve for some time after the charge has stopped. This is "useful" in the sense that a nickel-iron battery will deliver an appreciably greater capacity if discharged within several hours after a thorough recharge, than if allowed to stand until it has stopped gassing.

When cells are fully charged, at which time virtually all of the energy is dissipated as gas, the amount of hydrogen is about one cubic foot per cell for each 63 ampere hours of excess charge. The oxygen is one-half that amount. When hydrogen in the air reaches a proportion of about four percent it can constitute an explosive mixture. The above value can, therefore, be used to relate the approximate amount evolved from a given battery, to the size of the room or compartment in which it may be located.

13. VENTILATION

Proper ventilation of nickel-iron batteries is important both from the standpoint of avoiding high temperatures and the possible accumulation of hydrogen in hazardous quantities. The latter is seldon significant unless the battery is in a small enclosed area, but the temperature factor can be if the battery is in cycled service.

In most assemblies of these batteries the cells are separated by an air space of perhaps ½ inch to permit free air circulation between them. For the same reason they are suspended from the sides of the trays, rather than resting on the bottoms, in order that the bottoms may be entirely open. To take advantage of this construction, however, the compartment or space in which the battery is located must permit airflow through it. For example, an industrial truck battery thus constructed, but placed in an enclosed, non-ventilated compartment cannot usually be kept at a reasonable temperature.

These cells can be made in compact assemblies for use where space requirements are critical, but special means may be required to avoid high temperatures unless the discharge rates are low.

Ventilation is equally important during charge. When cycled batteries are charged out of a truck or other enclosed compartment, the charging rack or bench should be of open grille construction for free airflow. Fans may also be desirable to achieve the best results.

Each installation has its own requirements. If battery temperatures are higher than desirable, the manufacturer can best decide on the most effective and practical remedy.

14. INTERNAL RESISTANCE

Any battery cell has, of course, its own internal ohmic resistance, this consisting of the path through the active materials, plate frames, electrolyte and cell posts. While this resistance is usually low in comparison with that of the external load, it can be quite significant at high current rates of discharge.

The actual value is seldom used or required in practical battery applications, as the known voltage and current characteristics usually suffice. A general approximation, however, is a value of about .005 ohms for a fully charged 100 ah cell at normal temperature. During the latter half of discharge this will increase perhaps 50 percent. For cells of other ampere hour capacities, the value would vary inversely.

15. TESTS

The actual testing of battery condition or capacity is done by a discharge under controlled conditions. Such tests are made by manufacturers in line of research and production checking, but not by the average battery user. To indicate how capacity is thus determined, however, such discharge tests are conducted in the following manner.

The battery is completely recharged. A discharge rate is selected, depending on the load equipment and time available, the 5 hour rate being most commonly used to a final voltage of 1.0 per cell. If the test cannot be run at about the normal temperature of 77°F, corrections must be made. During the test the current must be continually maintained at the selected rate, and the proportion of time until final voltage is reached, compared to the rated time, represents the battery capacity.

Example: (assuming normal temperature and specific gravity.) It is desired to test a 24 cell, 450 ampere hour battery at the 5 hour rate. Current is $450 \div 5 = 90$ amperes. Final voltage is 24×1.0 volt $= 24$ volts. During the test the total battery voltage decreases to 24.0 volts in 4.4 hours. This is 88% of rated time of 5 hours, — therefore, battery has 88% capacity.

16. MAINTENANCE

While a nickel-iron battery requires comparatively little maintenance, what *is* required is very necessary to proper operation and long life. The following are the principal items to be considered:

a. *Proper Charging.* This is by far the most important factor in battery operation. See Sec. 8 and 9. Every effort should be made to give the correct amount of charge at proper rates and with adequate ventilation.

b. *Water Addition.* Approved water must be added at necessary intervals to maintain the electrolyte level between the tops of the plates and its specified height. DO NOT OVERFILL, as this may cause overflowing during charge.

Most public water supplies are satisfactory if drawn from a tap in frequent use, to avoid any accumulation of dirt or impurities from the pipes.

c. *Cleaning.* The battery must be kept reasonably clean and dry in order to avoid any paths of electrical "leakage" between adjoining cells, or from cells to conducting trays or boxes. Such leakage will cause electrolytic action, resulting in corrosion of the steel containers.

As necessary, these batteries should preferably be cleaned with steam or hot water and blown dry with compressed air. They should be raised off the floor when doing this in order that any dirt will be completely flushed away. Always keep filler caps closed during such cleaning.

If the battery location does not permit cleaning in the above manner, all portions should be wiped clean with a damp cloth.

After cleaning renew any of the protective coatings as necessary.

d. *Solution Change.* Over long periods of time the specific gravity of the electrolyte will decrease due to small amounts lost through spray, etc. When the corrected value falls to about 1.160 the entire contents of the cells should be replaced. The following routine should be followed.

Obtain a sufficient amount of "Renewal Solution," which has a specific gravity of 1.245 at 77°F. Discharge the battery completely and then short circuit it for a number of hours. Dump the old solution and replace with the new, followed by a recharge of about twice the normal length of time. (The manufacturer will furnish additional details.)

This solution renewal is usually necessary only perhaps twice during the battery's life.

e. If this type of battery is in very light use for a considerable period of time, or is not given sufficient charge, it may develop low capacity. This can usually be remedied by one or two "cycles" of discharge and recharge. Such a cycle consists of discharging the battery down to about one-half volt per cell and then short-circuiting it. This short-circuiting should be done individually or in groups of just a few cells. After being shorted for at least a few hours, remove the shorting leads and recharge at the specified rate for twice the normal length of time (equivalent to 2.5 or 3 times the rated ampere hour capacity of the battery.) The battery should then be restored to full capacity.

f. No physical overhauling or repairs are normally required during the life of the battery. In the event of accidental damage, the affected cells or the entire battery should be returned to the manufacturer for whatever attention is required.

17. STORAGE

If these batteries are to remain out of service for several months or longer, they should preferably be completely discharged, short-circuited, and left in that condition during the storage period. If this is not done, several "cycles" may be required to restore capacity.

First, of course, add water to normal level if necessary, to insure that plates remain covered. Also keep filling caps closed.

To prepare for use again, add water if necessary, remove short-circuiting jumpers, and give a recharge at specified rate for about twice the usual length of time (equivalent to 3 times the ampere hour rating).

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